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THE MODERN PHOTOGRAPHIC TELESCOPE AND THE NEW ASTRONOMICAL PHOTOGRAPHY

By G. W. RITCHEY

PART II.—THE RITCHEY-CHRÉTIEN REFLECTOR

In 1904 I published a memoir on *The Modern Reflecting Telescope and the Making and Testing of Optical Mirrors.*[1] In it I described fully, with many illustrations, the preliminary optical work on the mirrors, and the designs of a mounting, for a 60-inch reflecting telescope. This preliminary work was done at Yerkes Observatory, 1896-1904. These designs embodied all of the improvements in telescope design which I had developed up to that time. They included a new method of mechanical flotation of the large mirror; the efficient flotation of the polar axis and all that it carries, in mercury; the use of ground and polished worm-gears and tangent-screws for transmitting rotation to the polar axis; the interchange of several "extensions" of the skeleton tube, in order to make available several different focal lengths; a light, all-metal dome and building, with double, ventilated walls and other improvements which have proved to be of importance in astronomical photography. During the following four years, 1905-1908, through the munificence of Andrew Carnegie, I was able to carry out all of the details of that design, in the construction of the 60-inch Mount Wilson reflector. This work included the completion of the optical mirrors; the supervision of construction of the massive

[1]Ritchey, *Smithsonian Contributions to Knowledge*, Vol. 34, 1904.

parts of the mounting and dome at the shops of the Union Iron Works of San Francisco; the supervision of construction of the road up Mount Wilson; the transportation of the telescope dome and accessories to the summit, and their erection there. Immediately following, I used this telescope with extreme precision, for several years, in astronomical photography of nebulae, star-clusters and comets.[1]

I record the following facts because of the important developments in Astronomy which resulted from them. Mr. John D. Hooker, of Los Angeles, had taken a great interest in the establishment of the Mount Wilson Observatory. He was especially interested in astronomical photography and in the development of the modern reflector. He appreciated, more than any other man I ever knew, the fact that I had been able to photograph with the 24-inch Yerkes reflector the excessively faint, *expanding*, nebulous rings around *Nova Persei*, when they were entirely invisible with the 40-inch refractor; and also the fact that I had been able, with that small (and formerly despised) reflector, to photograph stars which are at least two magnitudes fainter than those at the visual limit of the 40-inch refractor.

Mr. Hooker had requested me to have large glass transparencies made for him from my Yerkes negatives taken with the 24-inch reflector and with the 40-inch refractor.[2] I had also designed and made for him a special cabinet, for his library, in which a large series of these transparencies could be seen, in succession, with fine illumination. Later, when my celestial photographs made with the 60-inch reflector became available, I added transparencies of scores of these to Mr. Hooker's collection. He had magnificent books, paintings, musical instruments, and gardens at his home; but he said to me: "neither literature, art, music, nor even flowers can sound the greatest depths of me, as these marvellous pictures of the heavens do."

In 1905 Percival Lowell consulted me in regard to a 7-foot reflector for the Lowell Observatory. In June of that year he

[1]Ritchey, *Astrophysical Journal*, Vol. 29, April, 1909, page 198; and Vol. 32, July, 1910, page 283.

[2]*Astrophysical Journal*, Vol. 12, 1900, page 352; also Vol. 14, November, 1901, page 217.

requested me to order for that purpose a 7-foot disk of glass from St. Gobain. After this order had been acknowledged and accepted by the St. Gobain Company, Mr. Lowell decided to postpone the project; later he had a smaller reflector constructed by the Clarks. But Mr. Hooker had become so interested in the construction of the 60-inch reflector and in Lowell's great project that he decided, when Lowell indefinitely postponed the latter, to adopt it as his own, and to give to Mount Wilson Observatory a sum of money sufficient to inaugurate the work on a telescope much larger than the 60-inch. At his request I corresponded with the St. Gobain Company, by cable, about an 8-foot disk to replace the 7-foot previously ordered for Mr. Lowell. When M. Delloye, Director-General of the St. Gobain Company, replied that he was willing to undertake an 8-foot disk, and upon my own expressed willingness to undertake the optical work and the mounting for a telescope of still larger aperture than 8 feet, Mr. Hooker requested me to cable St. Gobain: "Prepare immediately to cast a disk for a mirror to finish 100 inches aperture."

When the preparatory work for the 100-inch Hooker telescope was well advanced, Mr. Hooker decided to try to interest Mr. Carnegie personally in this great undertaking. As a result, Mr. Carnegie visited Mount Wilson and Los Angeles in the spring of 1910. Incidentally he became so interested in Mr Hooker's collection of astronomical transparencies that he requested me to prepare a similar collection, and a similar cabinet to exhibit them, for his New York home. When he received these in the autumn of that year he wrote me a letter of thanks. A few weeks thereafter he made an addition of $10,000,000 to the endowment of the Carnegie Institution, and expressed the wish that a sufficient part of the income of this gift be used for the completion of the 100-inch Hooker telescope and for its perpetual use.

Mr. Hooker's great and helpful interest in the development of the 100-inch reflector, and in every improvement which I, as the designer of it, had planned to incorporate in it and to prepare for use with it, continued until his sudden death in July, 1911. I record here my reverence for this great man, not because he was rich, but because he was good: a faithful friend, a kindly, honorable man, profoundly interested in the highest and noblest endeavour.

Later I shall give the complete history of the 100-inch disk and its accessory disks; of the optical work on these disks; of the 100-inch mounting, and of Mr. Hooker's and Mr. Carnegie's personal interest in, and high hopes for, the 100-inch telescope. What a marvellous, incomparable opportunity for Astronomy was there! And the use of the 60-inch, night after night, showing what was done, what to do! At present I shall say only that every detail of the optical work of the mirrors of the 100-inch reflector, including the daily, visual optical tests which determined every detail of the actual figuring, was done under my immediate personal care, with two assistants: Mr. Kinney, a highly-skilled wood-worker, and Mr. Dalton, an able machinist and electrician, both of whom I trained in optical work. This work, including the design and construction of the machinery, tools and special laboratory building for it, required the greater part of my time and intense care for five years. Some astronomers say, so easily, that the making of very large and very accurate optical surfaces is "merely a mechanical operation", whatever that may mean. We note that these astronomers have never made any.

The *general* design of the 100-inch mounting, including the use of the closed fork and the upper and lower floats (in mercury), is the work of my father, James Ritchey, and myself. All designs of *details* of the mounting, as actually constructed, are the work of others.

Necessity of New Types of Reflecting Telescopes

The questions of the type of mirror-combinations and of the design of mountings for the better and larger reflecting telescopes which are made possible by the cellular construction of mirrors, are of much interest and importance. Long experience in the use of the 60-inch Mount Wilson reflector showed the advantages of that type, but also showed the directions in which important improvements could be made. A long study of the *refinements* which are possible in the use of great reflectors in astronomical photography shows the absolute necessity of improved types of reflecting telescopes, in order that these refinements may be used efficiently, and to the utmost limit of their possibilities. The use of these

refinements is as indispensable for a great increase in accuracy of astronomical measurements as are more perfect and larger telescopes.

Most of my readers know of the principal types of reflectors developed in the past: Newtonian, Gregorian, Cassegrainian and Herschelian. These are described in the encyclopedias. For the best results the large concave mirror of each of these types must have a paraboloidal surface. Each type except the Herschelian requires a small secondary mirror also. In the Newtonian the surface of the secondary mirror is optically plane; in the Gregorian it is a concave ellipsoid; in the Cassegrainian it is a convex hyperboloid.

The reflecting telescopes of the Yerkes and Mount Wilson Observatories were so designed by the writer that they could be changed easily from the Newtonian to the Cassegrainian form, and *vice versa*; this is done by interchanging the short upper ends (called tube-extensions) of the skeleton tube; each of these interchangeable ends carries its own secondary mirror. The result is that the telescope has several interchangeable focal lengths. For example, the large concave mirror can have a focal ratio of 6 to 1; this ratio gives sufficient concentration of light for the photography of faint nebulae, for which the Newtonian arrangement of mirrors is used. By removing the Newtonian tube-extension with its small plane mirror, and substituting a Cassegrainian tube-extension with its small convex mirror, we can double the effective focal length; the equivalent focal ratio is now 12 to 1. The telescope is used in this form for the photography of brighter celestial objects and those requiring greater scale. Similarly we can remove this second tube-extension and substitute another Cassegrainian one having its secondary mirror slightly smaller and more highly convex than the other; we can thus triple the original focal length, so that the equivalent focal ratio is now 18 to 1; and so on.

It is seen that the small convex mirrors serve as magnifying mirrors, and that the usefulness of photographic reflecting telescopes is greatly increased by this system of interchangeable focal ratios.

1.—*The Ritchey-Chrétien Type*

In 1910, while I was engaged in astronomical photography with the 60-inch Mount Wilson reflector, M. Chrétien, of the *Observatoire de Nice*, visited Mount Wilson for several months for the purpose of studying the great reflector and its use. We then studied together many improvements which had been suggested by my use of the 60-inch telescope in astronomical photography.

I was then also in charge of the design of the 100-inch Hooker reflector. I was facing the necessity of a dome about 100 feet in diameter, and of a skeleton tube about 10 feet in diameter and about fifty feet long, if the general type of the 60-inch reflector were adopted for the 100-inch.

I had already experienced for a year the inconvenience of photographing at the Newtonian focus of the 60-inch,—of following the large movement of the upper end of the tube while making the innumerable, quick, small corrections with the double-slide plate-carrier, which are necessary to secure the sharpest possible photographs.[1] This difficulty is not merely one of personal inconvenience; it is indeed a fatal one to the most perfect guiding, unless it be met in some really effective way, as, for example, by the use of an observer's carriage moving exactly with the equatorial motion of the telescope. But this, of course, is not a simple problem in the case of a large Newtonian reflector.

I had seen for a year how sensitive is a great, highly-refined equatorial reflector to slight changes of temperature. In making the finest long-exposure photographs of nebulae, star-clusters, etc., I was compelled to cover with a diaphragm the outer zone 5 inches wide of the large mirror, (thus reducing the aperture to 50 inches), on account of the slight change of figure of this zone due to temperature changes. Further, I was compelled to find an extremely accurate method of refocusing very frequently during long exposures (the knife-edge method), in order to correct for the small changes of length of the tube, due to temperature changes. And for the finest results I was compelled to inclose the massive parts of the telescope, including the large mirror, in a constant-temperature chamber inside of the dome, during the day, to protect the

[1] A. A. Common, *Monthly Notices*, 49, page 297.

telescope from the large temperature change between day and night.[1]

I had seen for a year the necessity and the difficulty of *quick* interchanging of the tube-extensions which carry the various secondary mirrors. A simple and inexpensive mechanism suspended from the dome is sufficient for interchanging these tube-extensions during the day, when an abundance of time and help are available; but to make this change at night with safety, and quickly enough to take the fullest possible advantage of changing conditions with respect to atmospheric definition and to moonlight, requires, for large equatorial reflectors, special and very carefully-designed mechanism.

I had seen for a year how small is the measurable field of a short-focus paraboloidal mirror of large aperture and good figure, on account of the *coma* or aberration of the out-of-axis images. I had seen how accentuated this smallness of field appears in a great reflector as compared with that of a smaller one such as the 24 inch Yerkes reflector. In all of my use of the Yerkes reflector at the Newtonian focus, the field used was 108 minutes of arc square.[2] In my early work at the Newtonian focus of the 60-inch Mount Wilson reflector the size of field used was approximately 70 by 90 minutes of arc. It was soon evident that this field was much larger than was generally useful, the star images toward the edges having a very strongly-marked arrow-head form. Only for the discovery of large numbers of small, faint nebulae was it desirable to use so large a field. A new double-slide plate-carrier was designed and constructed, with many improvements which had been suggested by my early use of this telescope.[3]

The field of the new plate-carrier is only 38 minutes of arc (84 mm.), square; this includes all of the field which is generally useful at the Newtonian focus of the 60-inch reflector. For purposes of very exact measurement only, a circular field 15 minutes of arc (33 mm.) in diameter would be the maximum which could be used to advantage; and near the edge of even this field the star-images are not as small, intense and symmetrical in form as they

[1]Ritchey, *Astrophysical Journal*, Vol. 32, July, 1910, page 283.
[2]Ritchey, *Astrophysical Journal*, Vol. 14, November, 1901, page 217.
[3]Ritchey, *Astrophysical Journal*, Vol. 32, July, 1910, page 283.

should be for most accurate measurement, because of the aberration of all out-of-axis images at the Newtonian focus.

The great importance of the last-named difficulty, and of all of the others just described, becomes so marked in very large and refined instruments that I had made an intensive study with the object of finding methods by which these difficulties could be decreased or eliminated in the 100-inch reflector. It is true that fine results were being secured in astronomical photography at that time with the 60-inch reflector; but it was certain that all of the difficulties named would be accentuated in the 100-inch reflector if it were constructed on a similar plan.

Could we expect to find, by any possible good-fortune, a type of reflector in which *all* of the difficulties just described would be eliminated or greatly decreased? It was in the endeavour to do this that I suggested, and investigated with M. Chrétien, the possibilities of a very short, modified Cassegrainian type, with new curves of the mirror surfaces, in which the ratio of *equivalent* focal length to aperture woud be between 6 and 7 to 1, that is, small enough to permit the photography of very faint nebulae. It was evident that a Cassegrainian type in which the focal ratio of the large mirror would be 4 to 1, and in which the magnification given by the small convex mirror would be 1.6 or 1.7 times, would give the desired equivalent focal ratio of 6.4 or 6.8 to 1, and at the same time would give a very compact, light, rigid, economical type of mounting, requiring only a small and economical dome and building. The motion of the observer in following the focus, which would now be near the centre of motion of the telescope, would always be small and slow, thus insuring his convenience and safety, and greatly increasing his ability for rapid and skilful work. The shortness of the tube would make practicable many refinements which would enormously decrease its flexures and the effects of temperature changes, thus conserving the alignment and mutual adjustment of the two mirrors.

It was shown by mathematical investigation by Professor Chrétien that if we would confine ourselves, for the finest possible results, to a single equivalent focal ratio in a given telescope, by using always in combination a single pair of mirrors, large concave and small convex, with curves slightly different from the para-

boloid and hyperboloid, respectively, of the Cassegrainian, it would be possible to improve very greatly the field, and the smallness, light-concentration and symmetry of form of the out-of-axis

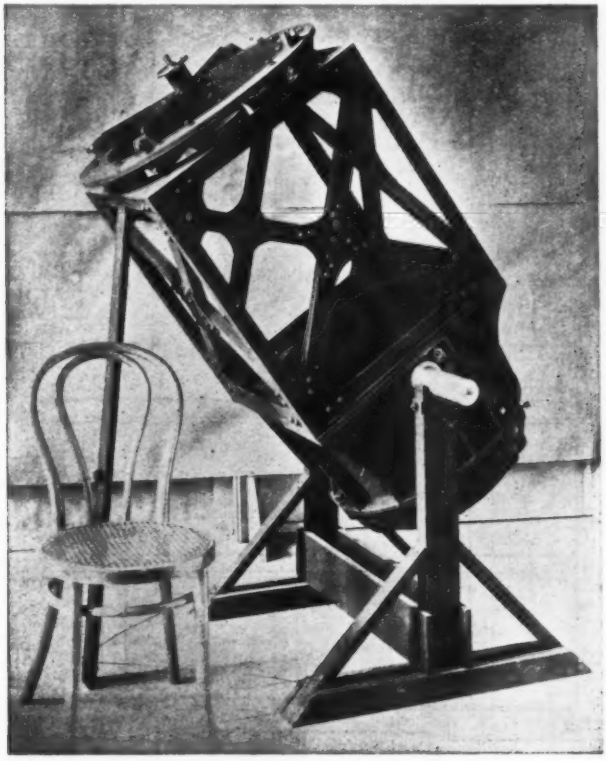

FIG. 5. First Model of Ritchey-Chrétien Aplanatic Telescope.

Diameter of large mirror, 50.5 cm., focal length 1.64 m. Second mirror, convex, diam. 18 cm., focal length, 1.11 m. Aperture is 1/6.8 of focal length of the combination.

images, of the short-focus reflector. The new combination of curves is especially chosen to eliminate entirely the *coma* of the out-of-axis images, while at the same time retaining the perfect central image.

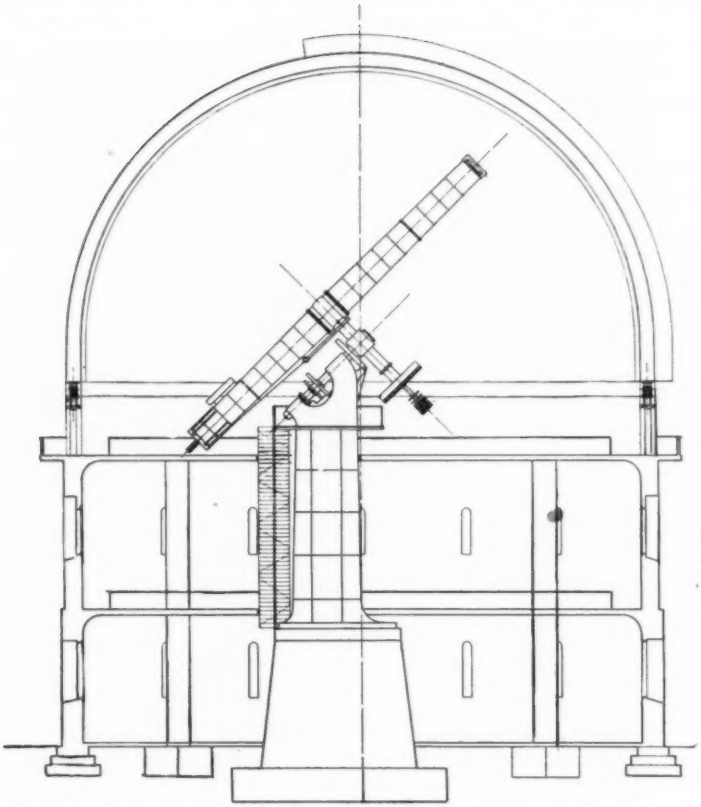

FIG. 6. Equatorial Refracting Telescope, Yerkes Type. Interior diameter of dome 26 metres. Aperture of telescope 1 metre. Compare with Fig. 7.

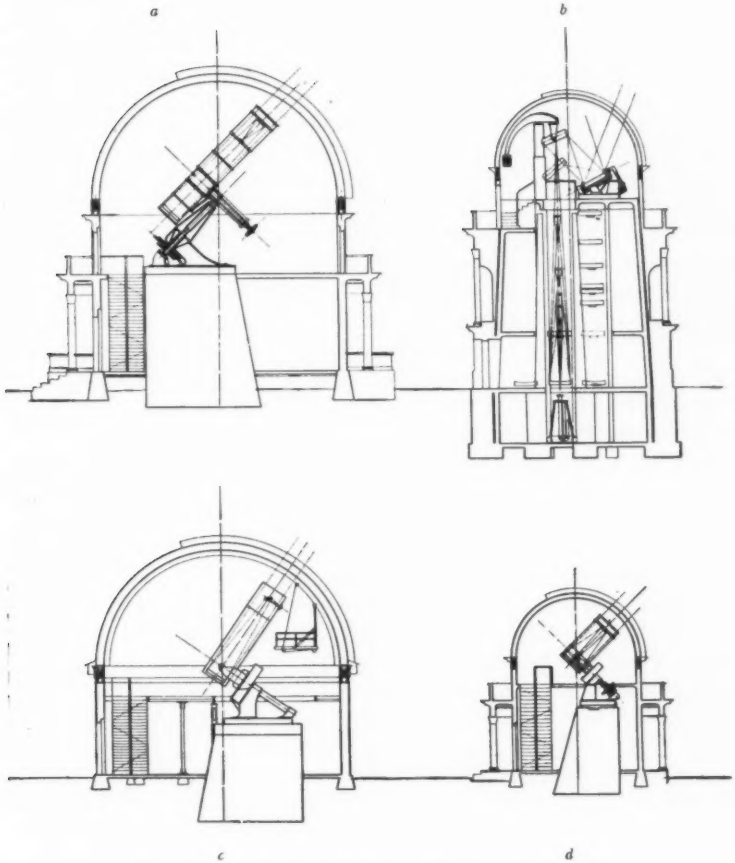

FIG. 7. Four Types of Reflectors, all of aperture 1 metre.
(*a*) Schwarzschild type; interior diameter of dome, 11 m.
(*b*) Ritchey Universal type; dome 6.5 m.
(*c*) Mount Wilson type; dome 11 m.
(*d*) Ritchey-Chrétien type; dome 5.5 m.

The most perfect field of extremely small images given by this combination is a slightly curved one, concave toward the incident light; so that, to realize the fullest possible advantage of this type we must use a slightly concave, spherical photographic plate, or a correcting-lens nearly in contact with a flat photographic plate.[1]

It is important to note that greater equivalent focal lengths can easily be secured with the *same* instrument, for spectrographic work and for direct photography with high powers, by substituting a second, and, if we wish, a third, small convex mirror in place of the first one. This is done by means of interchangeable tube-extensions, as already described. These second and third convex mirrors do not give so large a field as the first one gives, because, only one form of small convex mirror can be rigorously fitted or matched with a *given* large concave mirror, to secure the condition of entire freedom from *coma* of the out-of-axis images; but the second and third small convex mirrors do give practically perfect images at and near the centre of field.[2]

While investigating the character of the curves of the two-mirror combination required to secure the conditions described above, we availed ourselves of the remarkable memoir of Schwarzschild entitled "Theorie der Spiegeltelescope".[3]

Schwarzschild considers the case of a two-mirror reflector having a large concave and a small *concave* mirror used always in combination. His fine mathematical treatment of the problem is of a perfectly general character; his formulae, with the necessary changes of sign, are applicable in the case of the short, new-curve Cassegrainian type in which we are now especially interested, for reasons given more fully below.

In Schwarzschild's type he places his small concave mirror inside the focus of the principal mirror, and modifies the curves of both to secure the conditions of freedom from *coma* of the out-of-axis images, and at the same time, a perfect central image. He thus secures a large (angular) field of small, round images, together with a remarkably small ratio of focal length to aperture; as small as 3 to 1 or even 2.5 to 1, if desired. (Figs. 8(3).)

[1]H. Chrétien, *Revue d'Optique*, Paris, Tome I, 1922, I et II, pages 1-28.

[2]H. Chrétien, *Comptes rendus de l'Académie des Sciences*, November 21, 1927.

[3]K. Schwarzschild, *Theorie der Spiegeltelescope*, Potsdam, 1905.

Schwarzschild said to the writer, in 1910, that he regarded this telescope as a special type for a special purpose,—a small focal ratio with large field; that he did not consider it of general usefulness, because of its many practical difficulties. The considerable length of the telescope tube as compared with that of other modern

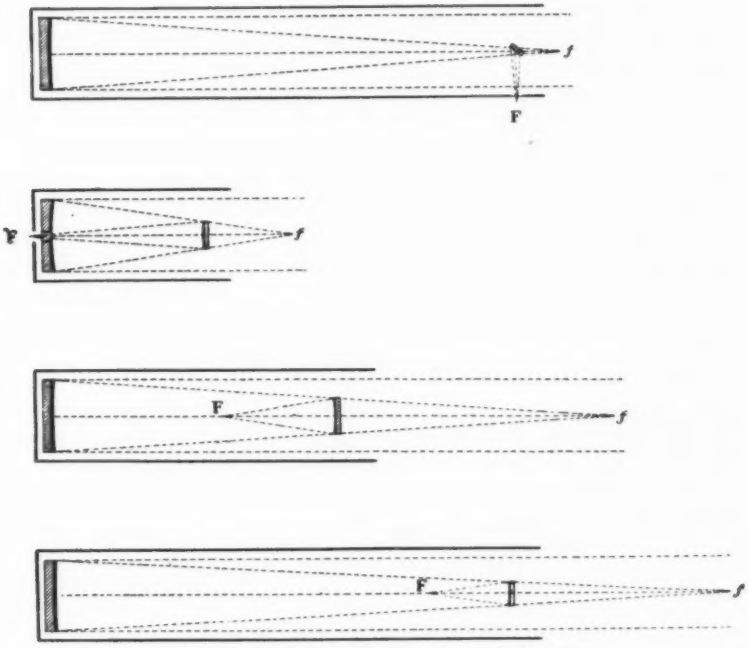

FIG. 8. Diagrams of Four Types of Reflectors.

1. (Top) Newtonian type; aperture $f/6.8$.
2. Ritchey-Chrétien type; aperture $f/6.8$.
3. Schwarzschild type, aplanatic with flat field; aperture $f/3$.
4. (Bot.) Aplanatic telescope with anastigmatic (convex) field; aperture $f/3$.

reflector types; the large size of the secondary concave mirror, which, in the form illustrated by Schwarzschild in his memoir, has about one-half the diameter of the principal mirror; the large percentage of light obstructed by this secondary mirror; the fact that the photographic plate must be in the axis and between the

two mirrors, thus obstructing to some extent the cone of light reflected from the principal mirror; the inaccessibility of the photographic plate-carrier for purposes of centering, focusing and selection of guide-stars, also for guiding, refocusing and correcting for rotation of field during long exposures; the difficulty of maintaining the necessary mutual alignment of the two mirrors, because of the flexures of the tube due to its length and to the weight of the relatively large secondary mirror and its cell;—all of these difficulties are strongly opposed to economy of construction and to efficiency and convenience in use. Some of these difficulties, however, disappear, while most of the others can be much diminished, when this telescope is constructed on a large scale and is used as a fixed telescope with coelostat.[1]

So far as the writer knows, Schwarzschild's type of telescope has never been completely demonstrated in use. It is one of the most important developments which should be fully demonstrated on a large scale in an *astronomical laboratory*; for it will give *revolutionary* results in photographing extremely faint stars and nebulosities with fine definition over a very large field. The scale of the photographs is small for purposes of most accurate measurement, compared with that given by other reflector types, because of the very small focal ratio; but this becomes relatively unimportant when this telescope is constructed on a large scale.

It is unaccountable that, so far as his memoir indicates, Schwarzschild did not consider the importance of the application of the general principles demonstrated in his memoir to the very short, modified Cassegrainian type. This *second* large-field, two-mirror type is the *Ritchey-Chrétien*. It differs from the Schwarzschild type in the following fundamental characteristics: (*a*) It is adapted, not for one special purpose only, but for the broadest general usefulness in astronomical photography. (*b*) Its arrangement of mirrors is such as to permit a most convenient form of equatorial telescope, the focus of the optical combination being in an accessible position near the centre of motion of the instrument, and never far above the floor of the dome. (*c*) The telescope tube is very short, and is therefore well adapted for the economical use of improvements which decrease its flexures and its expansion and con-

[1]Ritchey, *Comptes Rendus de l'Académie des Sciences*, 185, 1927, page 758.

traction at least a hundred times, thus insuring a corresponding degree of permanence of alignment and of separation of the two mirrors. (*d*) The principal equivalent focal ratio can be chosen as the best one for general photographic work: for example, a focal ratio of 6.4 or 6.8 to 1; for this we use the rigorous combination of new curves which give a maximum field of very small images without *coma*. Without changing the large mirror greater equivalent focal ratios are secured efficiently and economically whenever desired as explained above. (*e*) The small secondary mirrors are but little larger, in comparison with the principal mirror, than those of the ordinary Cassegrainian type. (*f*) There is no obstruction in the cone of light reflected from the large mirror. (*g*) The entire telescope is very compact in form, and is therefore well adapted for the complete and economical protection of all parts of it from the large changes of temperature during the day. (*h*) It permits the use of a dome and its supporting building, both of which are exceptionally small and economical.

A Comparison, in the Laboratory, of the Star-Images and Fields of the Newtonian and Ritchey-Chrétien Reflectors

In making the rigorous comparison described herewith of the images and fields of the two types of the reflector I have had the cordial support of the former Director of the Paris Observatory, M. B. Baillaud, and of the present Director, M. H. Deslandres. In addition, I have had the generous co-operation of Count de la Baume Pluvinel and of the St. Gobain Glass Company, through its Director-General, M. Delloye. The spirit of friendship and appreciation shown by French scientific men is herewith gratefully acknowledged.

In the Dina optical laboratory of the Paris Observatory I made the mirrors of a Newtonian reflector and also those of an aplanatic reflector of the Ritchey-Chrétien type. Each of these has an aperture of 19.9 inches and a focal length of 136 inches.[1] My purpose was to compare rigorously the star images and fields of the two types of telescope, and to do this in the laboratory, where

[1]This focal length is approximately that of the photographic refractors used for the *Carte du Ciel*.

nearly perfect conditions of quiet air and constant temperature could be maintained.

After the optical surfaces were completed and silvered, each system of mirrors, in succession, was set up on an all-metal optical bench, in combination with an optically plane, silvered mirror of 30 inches diameter. The similar use of a large plane mirror in the optical testing of Newtonian and Cassegrainian reflectors has been fully described by the writer.[1] The 30-inch plane mirror used in this comparison is of the built-up, cellular construction, and has retained its optical figure for three years without change which can be detected by the most sensitive optical tests.

The artificial star used in this comparison is approximately one micron in diameter, and is produced by the use of a tungsten-arc lamp, a small needle-hole and a microscope objective. In each telescope the artificial star remains always fixed, at the focus, in the axis. If the telescope mirrors are in good alignment, and if the large plane mirror is at right angles to the axis of the telescope, the light from the artificial star, after reflection by the telescope mirrors, then by the large plane mirror, and again by the telescope mirrors in reverse order, forms a reflected image or focus precisely at the position of the artificial star. If now the large plane mirror be rotated slightly about a vertical axis, the reflected image is formed at one side of the artificial star and of the axis. The arrangement of parts is such that the reflected images can be examined in all positions between the limits 2′.5 and 60′ from the axis.

The reflected images are examined by means of a microscope magnifying 100 diameters, and having a micrometer-eyepiece. This microscope can be clamped in any position between 2′.5 and 60′ from the axis of each telescope; its focal setting (in the direction parallel to its own axis) is determined by means of a micrometer, reading to 0.01 millimetre, and by a Brown and Sharpe straight-edge of the finest quality. The microscope thus serves for studying and measuring the out-of-axis images, and also for determining the curvature of the field of best images, of each telescope.

In Fig. 9 we see the 19.9 inch Ritchey-Chrétien concave mirror at the right, the cell containing the convex mirror of 7.2 inches

[1]Ritchey, *Astrophysical Journal*, Vol. 19, 1904, page 53; and *Smithsonian Contributions*, Vol. 34, 1904.

diameter at the left, and the 30 inch cellular plane mirror at the extreme left. The distance between the vertices of the two curved mirrors is 41.75 inches. The microscope is not shown, as it is behind the concave mirror.

In examining with the microscope the images formed at different distances from the axis, I have in each case chosen and recorded the focal setting at which the largest percentage of the total light of each image is concentrated in the smallest area. This practical

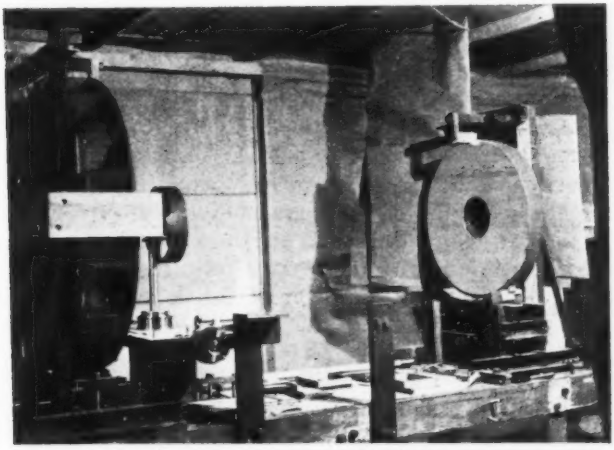

FIG. 9. The Mirrors of the first Ritchey-Chrétien Telescope at the Paris Observatory.

The mirrors are arranged on the optical bench used for comparative tests. The 30-inch plane mirror at the left is of the cellular (built-up) type.

procedure differs from theoretical investigations of the subject in that it necessarily takes full account of the *distribution* of light in the image, due to the combined effects of aberration and diffraction. The images thus selected I shall call images of *maximum concentration*.

Images and Field of the Newtonian Reflector

The out-of-axis images have the familiar, arrow-head form, that is, with coma; the point or vertex of the arrow-head being

always toward the centre of the field. The size of these images is, in general, directly proportional to their distance from the axis. But their form, and the distribution of light in them, changes markedly with small changes of focus.

In the *flat* Newtonian field used in astronomical photography at present a large percentage of the light of each image, at all distances from 5′ to 60′ from the axis, is distributed fairly uniformly over approximately one-half of its length which is adjacent to its vertex; one-fourth or more of the light of each image is in the two strong, curved rays which form its boundaries; there is no very marked concentration of light at its vertex. (Fig. 10, left-hand vertical column.) Unfortunately, the fraction "approximately one-half" just used is not constant, but varies with the *brightness* of the star, becoming larger for bright stars and *vice versa*. This and other properties of the Newtonian images absolutely prohibit very high accuracy of measurement of Newtonian photographs.

If we now move the eye-piece gradually forward from its position for the flat field, we see that the angle of the vertex of the out-of-axis image increases, the two side rays become fainter and more nearly straight, and the light of the image becomes more and more concentrated at and near its vertex, until we reach the focus of maximum concentration. (Fig. 10, central vertical column). The field or locus of these images of maximum concentration is, unfortunately, not a spherical surface, but is an approximate hyperboloid, concave toward the incident light. If we compare the out-of-axis images in this best curved field with the corresponding ones in the flat field exclusively used at present, we find that the gain in concentration of light in favour of the former is about quadruple, the area of concentration being about one-forth. This proportion holds, very approximately, for images at all distances between 5′ and 60′ from the axis, in the case of a Newtonian reflector of the dimensions given on page 221. Fig. 10 shows the comparison of the images at various distances from the axis in the flat and concave Newtonian fields. The angular dimensions of the images are indicated by the scale below.

In a Newtonian reflector of the dimensions given above, in which one minute of arc at the focus equals very nearly one millimeter, the perpendicular distances in front of the flat field to the

images of greatest concentration are approximately as follows: at 5′ from the axis, 0.035 millimetre, at 10′, 20′, 30′, 40′, 50′, and 60′ from the axis, 0.09, 0.22, 0.37, 0.52, 0.69 and 0.86 millimetre,

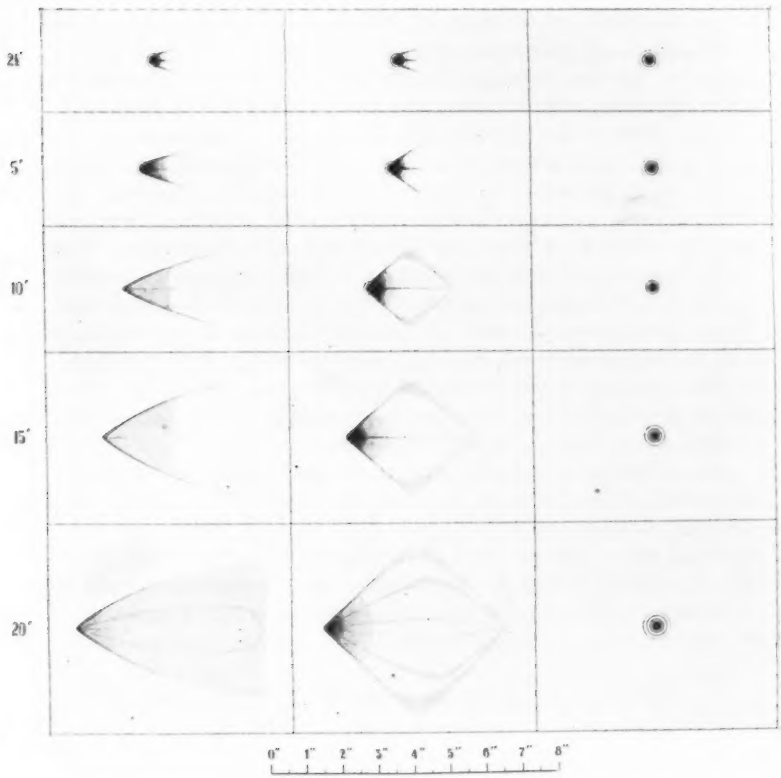

FIG. 10. Comparison, in the Laboratory, of stellar Images from 2½′ to 60′ from the Axis or the Centre of the Field.
(*a*) Left vertical column: Newtonian images in the ordinary flat field.
(*b*) Middle vertical column: Newtonian images in the concave hyperboloidal field.
(*c*) Right vertical column: Ritchey-Chrétien images in the concave spherical field.

respectively. Although the curvature of the best field is slight, it is of very great importance. (See page 227, at bottom).

By the use of a lens of proper form, made preferably of boro-

silicate crown glass, and placed close in front of a flat photographic plate, the effect of curvature of the field can be corrected in great part, but at the cost of considerable loss of light; this will be discussed later. On the other hand, concave photographic plates, to be used without such a correcting lens, can be made accurately and economically, in multiple, by cutting circular disks from sheets of thin, polished, selected plate-glass; softening them very slightly by heat; pressing them to the required hyperboloidal curve by means of highly polished steel dies; re-annealing them; and finally coating them on the concave side with sensitive emulsion.[1]

In my private laboratory I have made highly-accurate, spherical, concave photographic plates, by cutting circular disks from thin, polished plate-glass, then grinding and polishing them, in multiple (fifty at a time), to the desired spherical curve. The methods used are similar to those which I employed in the multiple-production of lenses and prisms for the United States Ordnance Department during the war. I have coated these concave surfaces with photographic emulsion, and have secured uniform thickness of the coating of emulsion by rotating the concave plates at the proper speed while the emulsion was setting. The details of this process will be given in a forthcoming paper.

In a Newtonian reflector of the dimensions given above, and for a field 2° in diameter, the concave photographic plate with spherical surface coinciding best with the hyperboloidal field described above has a radius of curvature of 64.57 inches. Similarly, for fields 1° and 30′ in diameter the corresponding radii of curvature of smaller spherical concave plates are 38.2 inches and 24.0 inches, respectively.

Images and Field of the Ritchey-Chrétien Reflector

I describe herewith the images observed in the optical tests of the new-type telescope of 19.9 inches clear aperture and 136 inches focal length. The large concave mirror has a focal ratio of 3.25 to 1; the small convex mirror magnifies 2.1 times; the equivalent focal ratio is therefore 6.825 to 1. The focus F (Fig. 8),

[1]The Saint-Gobain Company makes curved glass plates of very fine quality, for various commercial purposes, by pressing them to the proper form in this manner.

is at a point 6.3 inches back of the vertex of the optical surface of the large mirror; the distance between the vertices of the optical surfaces of the two mirrors is 41.73 inches; the diameter of the central hole in the large mirror, to allow for field and for exterior guide-stars, is 4.9 inches; the clear aperture of the small convex mirror is 7.1 inches.

The field or locus of the images of maximum concentration is spherical, concave toward the incident light; its radius of curvature is 23.62 inches. In this curved field each of the images at the distances 2′.5, 5′.0, 7′.5, and 10′.0 from the axis appears as a normal, brilliant diffraction disk of 0″.28 diameter, surrounded by normal diffraction rings. What is most remarkable, each of the images at the distances, 12′.5 15′.0, 17′.5 and 20′.0 from the axis also appears as a brilliant diffraction disk of about 0″.28 diameter, with its diffraction rings. But in these latter images the diffraction rings become slightly and progressively brighter; this is unquestionably due to the presence of the aberration-pattern, very small and symmetrical in form, which, at the distance of 20′ from the axis, is 0″.9 in diameter. It is not until we reach the distance 22′.5 from the axis that the appearance of the images is distinctly changed by the aberration-pattern. At greater distances from the axis the form and size of the images of course are determined more and more by the aberration-pattern. In the best curved field this form is always approximately circular; the illumination of the images is approximately symmetrical both radially and tangentially with respect to the centre of the field; the diameters of the aberration images vary as the square of their distances from the axis; and at the distances 30′, 45′ and 60′ from the axis these diameters are 2″.0, 4″.5 and 8″.0, respectively.

In Fig. 10 the left-hand vertical column shows the appearance of the Newtonian images in the flat field almost exclusively used in astronomical photography at present, at distances of 2′.5, 5′.0, 10′.0, 15′.0 and 20′.0 from the axis; the central vertical column shows the corresponding Newtonian images in the best concave (hyperboloidal) field; the right-hand column shows the corresponding Ritchey-Chrétien images in the best concave (spherical) field.

It seems superfluous to state that even with the types of photo-

graphic telescopes in use at present, a very great gain can be made without serious expense by using photographic plates the glass surfaces of which have been ground and polished approximately flat, or to the curvature of the best field.[1] When the observer becomes expert in the use of the knife-edge focusing device used with the 60-inch Mount Wilson reflector, the focal plane of the image of a star in the axis of that telescope can quickly be determined within 0.001 inch.[2] The irregularities of surface of the commercial photographic plates almost exclusively used in astronomical photography at present are from 5 to 30 times greater than the amount just named, depending, in part, upon the size of plates used; the results are: loss of sharpness of details photographed, loss in accuracy of measurement of the photographs, and the total loss of hundreds or thousands of the faintest star-images which would otherwise be recorded in long-exposure photographs. I include a table copied from one of my articles (on the 60-inch reflector) in the *Astrophysical Journal*,[2] which shows, for slight errors in focus, the theoretical loss in magnitudes per unit area in the cross-section of the luminous cone where it intersects the sensitive film. As shown by the table, this loss is so great that the surface-intensity must certainly fall below the necessary *threshold* value for great numbers of faint stars which under conditions of perfect focus would be impressed on the photographic plate. This table is based on the following constants of the 60-inch Mount Wilson reflector: ratio of focal length to aperture, 5 to 1; scale, 1 millimetre at the focus = 27″.2; theoretical diameter of diffraction disk of star in the axis (photographic), = 0″.074.

Error in Focus	Increase in Diameter of Cone	Total Diameter of Cone	Δm = Loss in Magnitudes
inch mm.	mm. ″	″	
0.001 = 0.025	0.005 = 0.136	0.210	2.27
2 = 0.050	0.010 = 0.272	0.346	3.35
3 = 0.075	0.015 = 0.408	0.482	4.07
4 = 0.100	0.020 = 0.544	0.618	4.60
0.005 = 0.125	0.025 = 0.680	0.754	5.04

[1] In the case of the photographic plates used for the Carte du Ciel, all of those which were used in France, and those which were supplied by France for foreign observatories, had the sensitive emulsion coated on thin, square sheets of ground and polished plate-glass.

[2] *Astrophysical Journal*, Vol. 32, page 287.

While atmosphere conditions at Mount Wilson seldom permit the theoretical condition corresponding to perfect focus to be realized, the table shows the enormous importance of the utmost attainable accuracy of focusing, and of protection from all conditions such as changes of temperature and flexure, which injuriously affect this accuracy; especially is this true when we are dealing with large angular apertures. This is a good general illustration of the importance of *all* of the great *refinements* which, I constantly insist, are even more important than great apertures. Let critics who say that these refinements are too technical, and especially *too laborious*, to be practicable, get what support they can from this table.

The Ritchey-Chrétien reflector permits a very great improvement to be made in accuracy of measurement of astronomical photographs, and in the faintness of out-of-axis stars which can be photographed with a given aperture. But in order to utilize to the fullest possible degree these advantages, which are due chiefly to the very small, symmetrical star-images given by this telescope, we must use the necessary refinements both of photographic plates and of the mechanical parts and accessories of the teslecope.

Photographic Plates for the Ritchey-Chrétien Reflector

Leaving aside for the present the enormously important subject of special photographic emulsions for astronomical photography, it is clear that we must use either photographic plates, the glass surfaces of which are ground and polished flat, in combination with a correcting lens for rendering the field flat; or on the other hand, photographic plates the glass surfaces of which are ground and polished to a spherical surface of the proper radius of curvature. The writer prefers the latter method, because of the light which is lost by reflection from at least two surfaces of a correcting lens, and *far more*, because of the loss of photographic (blue) light by absorption in even the best correcting lens; the great importance of this point will be considered later. It should be noticed that in the Ritchey-Chrétien telescope there are only two reflections, both from silvered mirrors. The ground and polished, circular glass bases for the spherically-concave photo-

graphic plates which I have prepared for the 19.9-inch new-type telescope are 3.5 inches (about 90 minutes of arc at the focus) in clear diameter. The depth of the concave surface of these plates is 0.065 inch.

One of my greatest ambitions has been to develop a type of reflector of universal usefulness, which would combine great optical power and refinement with great economy and convenience of all mechanical parts. In the next article of this series I shall describe some of the refinements and economies of the *mechanical* parts and accessories of the Ritchey-Chrétien equatorial reflector, which are made possible by its general form and by the shortness of its tube and smallness of its dome. I shall then describe a Ritchey-Chrétien equatorial of 40-inches aperture, having one principal mirror and two small secondary (convex) mirrors. The first convex mirror gives a rigorous "aplanatic" field, and a focal length of 22.67 feet; the second convex mirror gives an *approximate* aplanatic field, and a focal length of 40 feet (see page 218). The over-all length of tube for the 22.67 feet focal length is 10.5 feet; the over-all length of tube for the 40-feet focal length is 11.8 feet. In order to accomodate well the longer tube-extensions, the interior diameter of the dome is 21 feet. In a still later article of this series, when I shall have described others of the refinements, formerly despised and rejected, the usefulness of which has now been demonstrated, I shall show how and why this modern 40-inch reflector, so compact and economical that it will be within the reach of scores or hundreds of observatories with moderate means (instead of only a few great observatories), will enable us to make photographs of fields of stars (fields large or small), of star-clusters, of spiral nebulae, etc., which for all purposes of highly-accurate measurement of star-positions will surpass the most perfect photographs which can be made with any telescope in use at present.

Paris Observatory, April 14, 1928.

RADIO TALKS ON ASTRONOMY, OVER CFCT, VICTORIA, B.C.

By W. E. Harper

V. The Age of the Earth

(April 11, 1928)

At a meeting of the Astronomical Society about two weeks ago I was asked to answer in a brief way this question of the age of the earth. I have felt that the answer I gave then might be enlarged upon to serve the occasion of this 10-minute talk and incidentally to bring to a larger audience the known facts as to the great age of the planet on which we live.

The best theory we have for the origin of the earth is that it, with the other planets, was torn from a vast nebulous mass by the close approach of a passing star. These isolated masses which later condensed to form planets must have at the start been intensely hot. Through long ages they cooled and contracted, becoming at first like lava and later solidifying into rock. The time required for such a process must be left with the physicist who calculates the rate of loss of heat from the body and deduces the time required for the internal store of heat to be used up.

In this way the English geophysicist, Jeffreys, has worked out that the earth would become, for the most part, encrusted over probably 10,000 years after the disruption,—a space of time which is relatively short, considered from an astronomical viewpoint. The surrounding atmosphere must originally have been very extensive, containing all the water of the ocean in a state of vapour. It, too, would also rapidly cool and in a few thousand years more would condense out and form oceans upon the surface. Within less than 100,000 years of the original catastrophe, then, it would appear that a mass initially gaseous but similar in size and composition to the earth would become a planet much like our own.

That is about as much as can be said on that phase of the question. The rest of the problem is to tell how long ago such a

condition existed, and to do that we must call to our aid, amongst others, the geologists whose business it is to study the rocks of the earth and the fossils imbedded in them.

It may be stated at the outset that there are three main lines of evidence that give us clues to the time interval which has elapsed since a crust formed over the earth. (1) The accumulation of the sedimentary rocks, (2) The saltiness of the ocean, and (3) The amounts of the elements uranium and lead in the earliest known rocks. A word about each.

(1) We know that due to wind and rain, to snow and frost the whole continental structure is being worn down and the sediment carried by the rivers finds its way to the lowest level. I repeat that the mountains are being "mawed" down by such erosive action and the resulting sediment which is deposited by the rivers in lakes and seas eventually solidifies into these so-called sedimentary rocks. And just as we can tell the age of a tree by counting the number of rings in a cross-section of its trunk, so by counting the strata or layers in a certain thickness of rock we can decipher how long that rock was in the process of formation. One foot of such rock corresponds to the deposits of about 2000 years. A thickness of 100,000 feet, such as exist in the earliest pre-Cambrian formations, would suggest, then, a period of 200 million years since the weathering influences began to come into play. This estimate is on the assumption that the geological processes of erosion and deposition were carried out at the same rate in the past as they are at present, and such a result may be looked upon as a lower limit to the interval that has elapsed.

(2) We know that the waters of the ocean contain enormous quantities of various salts in solution. These have presumably been dissolved out from the rocks, carried down by the rivers and deposited in the oceans. Ordinary salt is one of the most common constituents. From analysis of samples of sea water all over the world we know the total amount of salt at present in the ocean. The amount that is dissolved out yearly and carried down to the sea is more difficult to determine. In certain localities moisture laden winds from the ocean return a small amount to the land, but the percentage is too small to have much bearing on the problem.

Calculating the amount that is carried down yearly in solution and dividing that into the total amount known to be present in the ocean, we arrive at a second determination of the earth's age,—the result being slightly over 100 million years. This estimate is on the assumption that initially the waters of the ocean were fresh and, moreover, that the rate in the past was the same as at present. If it were slower at the start, as is likely, the time interval would be increased.

(3) For the third line of evidence, we must summon the physicists and chemists to our assistance. Certain of the heavier elements like thorium and uranium are found to be radio-active; that is, they are gradually disintegrating and changing into other substances. After losing about one-seventh of its mass in the form of ejected particles, the heaviest known metal uranium, eventually ends up as lead, but lead of a character which can be distinguished chemically from the ordinary kind. The rate of this change does not vary with the temperature or pressure, and although very slow, can be measured accurately. Hence by taking a sample of rock and determining its percentage composition of uranium and this special kind of lead we can deduce the approximate age of those particular rocks. Such evidence is in accord with that from other sources as to the relative ages of our rocks. Those rocks laid down in the age when the dinosaurs had died off yield values of 60 millions of years; those of an earlier epoch when our coal beds were laid down suggest 250 million years, whilst the pre-Cambrian rocks which go back to the time of the earliest fossils are from 500 to 600 million years old.

Recently an English physicist has been able to analyze the composition of the oldest rocks by a new and very precise method, and on the assumption that the lead in the earth's crust has come from the gradual decomposition of the heavier metals in this radio-active manner he has been led to assign 4800 million years as a maximum limit of the age of the earth. Thus we have estimates of the oldest rocks indicating ages from 1000 to nearly 5000 millions of years, while the period since plants and mammals made their appearance on the earth may be set down as 50 or 60 million years.

These are the best determinations we have at present. Future

discoveries may change them somewhat but not to any marked degree, and the exceeding great age of our planet may be considered as one of the great established truths.

Of course, one need hardly remind you, in conclusion, that it is only a comparatively short time since man's advent upon the earth.

VI. The Northern Lights; What Are They?
(April 25, 1928)

This evening I wish to bring to you in the 10 minutes at my disposal our knowledge of the aurora or Northern Lights as they are popularly called. As it is quite possible that we may be favoured with an auroral display before long, the subject would seem to be a timely one. In passing, I may suggest that a similar phenomenon is seen in the southern hemisphere, near the south pole, so that *polar* lights would be a more general term to use in speaking of them.

As one beholds a brilliant aurora with its dancing, shooting streamers and the accompanying colour display of vivid red or green, one is led to wonder as to its cause. When I was a boy, back in old Ontario, I remember we used to be told they were caused by sunlight reflected from the Arctic icebergs, or something to that effect. It is not so long ago, either, that they were looked upon by superstitious people as foretelling some dire catastrophe to come upon the earth. We have a suggestion of this prevailing dread in the two lines which occur to me from the poem "Edinburgh After Flodden"—

> "All last night the Northern Streamers shot across the trembling sky,
> Fearful lights that never beacon save when kings and heroes die."

Well, we have advanced a good deal since those days and now know something definite as to their cause, though our knowledge is not as complete as we could wish it to be. In a few years, after some of the budding scientists who are listening to me have tackled the remaining problems, we may expect a more complete elucidation of the whole phenomenon.

Let me mention, though, a few facts that have already been

found out, simply from observation. First, they occur only in high latitudes. At the equator none at all are seen. In southern California, Florida and at corresponding latitudes in Europe and Asia there is on the average only one aurora visible every ten years. In our own Victoria district, in the northern States, New York and central England they are 100 times as frequent, whilst in northern British Columbia, the northern prairie sections, Labrador and Norway we have their most frequent occurrence. Californians may have many things of which they can be justly proud, but their publicity literature cannot truthfully contain any reference to the beauties of the night sky, such as is ours, when Nature stages one of her remarkable displays. I wonder if our publicity agents have failed to take note of this.

The second fact to which I direct your attention is that they are more frequent and brilliant in some years than in others. For some years, as of late, they are seen but rarely; then they begin to increase in number until they reach a maximum. Afterwards they become fewer in number until a minimum is again reached. This period, determined from a long series of observations, takes between 11 and 12 years to run its course, and as the last maximum occurred in 1917 we ought to expect an increasing number of aurorae to be seen in this, and in the following year or two.

Now it so happens that astronomers studying, with their telescopes, the sun's surface have found that it, too, undergoes regularly recurring changes in this same identical period of time. The natural conclusion to which one would come is that the two phenomena are in some way related to each other. The sun, you know, is a glowing mass of gas of enormous size with a surface temperature of 6000° centigrade and of increasing higher temperature as we penetrate to its interior. The changes to which I have alluded are in the nature of violent eruptions of its surface much like volcanoes on the earth. From time to time, due to some disturbance in the interior, an eruption occurs and through this opening the gases and vapors from within are projected outwards with exceedingly high velocities.

Now the sun makes one complete rotation on its axis in 25 days, and when one of these disturbed areas, or spots as they are

called, is directly facing us it often happens that the Northern Lights are seen shortly afterwards. Thus over a number of years a remarkable series of such coincidences have been established between these sun spot upheavals and auroral displays.

In a similar way, telegraph operators and others have noted that at such times of marked displays there are electric currents traversing the earth which sometimes disorganize the whole telegraph system. It has thus been impressed upon us that the Northern Lights are in some way caused by the eruptions taking place on the sun's surface and that most likely electrified particles are discharged from the spots and eventually reach the earth.

Without going into too much detail we can explain this a little more to your satisfaction. In the modern conception of matter every atom consists of a nucleus, relatively massive and positively charged, with one or more negatively charged particles of small mass in attendance upon it. Shot outwards from the sun spot with velocities of several hundred miles per second the atoms are so badly knocked about that many of them are torn asunder or dissociated. The negative and positive electrified particles thus part close company and travel outwards separately. If this stream of particles is directed towards the earth then, after the lapse of a short time, they will plunge into its atmosphere. It is the bombardment of the rarefied gases of our upper atmosphere by these electrified particles, then, that produces the Northern Lights. The positively charged particles, being much the more massive, penetrate our atmosphere to a much greater depth than do the lighter, negative ones. One can imagine, then, where the electric currents that traverse the earth have their origin. Once more, putting it briefly, the aurora is caused by the bombardment of our upper atmosphere by electrified particles shot off from sun spots.

Our atmosphere consists principally of nitrogen and oxygen with smaller amounts of other gases. The analyzed light or spectrum of the aurora, then, should correspond with the spectra of nitrogen and oxygen, when they are excited to luminescence in our laboratories. There are many corresponding features, but up until a few years ago the strongest line of all in the auroral spectrum, one in the green region, could not be obtained from either nitrogen or

oxygen and its source was unknown. But in 1925 McLennan and Schrum at the University of Toronto succeeded in showing that oxygen under very rarefied and special conditions would give rise to the line.

This brings us to consider the conditions as to pressure and density of the gases in our atmosphere where the auroral light has its source. How high up in our atmosphere does the light occur? We do not see aurorae on cloudy nights, hence the phenomenon must occur higher up than the clouds. It is possible to obtain their heights by stationing, a few miles apart, two observers who will at the same instant note the position of some particular detail of the aurora with reference to the background of the stars. From hundreds of such observations made in Norway the average height of the lowest point of the aurora is 66 miles. But do not conclude that aurorae never come closer to the earth than this. Cases are known in the Yukon, where great displays are frequent, of an aurora being seen only a few hundred feet from the earth's surface. It would be a very desirable piece of work to have the heights of aurorae determined in Canada.

It has often been stated that, in brilliant displays, sounds are heard like the rustling of silk or the crash of breaking glass. Some people stoutly declare they have heard such sounds, while others are equally emphatic that such are never heard. While I have never heard them myself, I am prepared to accept the idea that noises do accompany brilliant aurorae. I have talked with our surveyors in the Yukon who undertook to test out a certain one of their number who stated he could hear such sounds. During a brilliant display they blindfolded him perfectly, but with each brilliant flash he would instantly exclaim "There it is; don't you hear it?" It would seem as if some people have ears attuned to catch these sounds better than others.

I stated at the start that we might be favoured with an auroral display before long. My reason for saying so is simply that the number of spots is greatly on the increase and sooner or later one will be directed toward us, belching out a swarm of electrified particles in our direction.

At our observatory we are not equipped for any special study

of the sun, but where they are, as at Mount Wilson, California, they can predict just where a spot is likely to appear upon the sun's surface. While you and I cannot do that, we can all examine the sun's surface from time to time to see these spots, taking care to protect our eyes by using smoked glass or a piece of over-smoked photographic film. It will be an interesting pastime to follow their course across the sun's disk and see when they are likely to bombard us.

VII. The Ursa Major Star Group
(May 9, 1928)

I have thought some of my hearers might be interested in a description of one of the chief groups of stars visible at all places within the reach of my voice. I can not claim any special qualification for giving such a talk, as in my own work with the big telescope we rarely examine the sky unless the star begins to dim in the telescope and we look out to see if clouds are coming up. However, some years ago in the East I was interested in a group of Boy Scouts, and the pleasure they seemed to derive from knowing the star groups and being able to use them as guides convinces me that there may be some of my younger hearers at least who will listen for ten mniutes to a description of one of the groups.

To those who would thus become acquainted with the stars, two things must be remembered. First, due to the rotation of the earth on its axis from west to east, once each day, the stars, like the sun, appear to rise in the east, to move across the heavens and to set in the west. This axis about which the earth is spinning would, if produced, cut the sky in two points, the poles, and near the north pole is a bright star we designate the pole star or Polaris. Those stars near the pole will describe small circles about it, others more distant will describe larger circles, the circular sweeps of the sky becoming larger and larger until we come half-way between the poles to the equator. Thus if you note a certain star in a definite position of the sky to-night, at nine o'clock, say, do not expect to see it there at twelve 'clock. It will have moved, as we say, three hours west or 3/24ths of the whole circle of the heavens.

The second thing we must keep in mind is that the stars of summer are different to the stars of winter. In our latitude the pole star is a little over half-way up from the horizon to the zenith. To be exact it is 48½°. All stars nearer the pole than this, as they circle about it, will never sink below the horizon but will occupy different positions in the northern heavens, depending upon the time of year. All others of course actually sink below the horizon and for portions of the year are never visible at any time of the night. A moment's consideration will show us why this is. Looking out south, say, at midnight to-night we are looking directly away from the sun into a certain region of space with its characteristic star groups. Six months later when we have been carried around to the other side of the sun, we would, on repeating the observation, be looking in a diametrically opposite direction and would thus see different star groups. Yes, the star groups seen keep gradually changing with the seasons.

In starting, no better course can be followed than the old-fashioned one of tracing the oultine of the seven bright stars known on the American continent as the "Great Dipper". In England this group goes by the name of "Charles' Wain" or "The Plough". Everyone presumably knows this group—if not, the first person one asks can generally point it out, and it is of the utmost importance that it be correctly located, as it is the starting point in learning the stars. At the present hour it is, to those likely to be listening in, almost overhead though slightly to the north and east. The seven bright stars form the outline of a dipper, three comprising the handle and four the bowl of the dipper. The handle is to the east of the bowl, while the bowl itself is facing the north. The two stars where the water would pour out of the dipper are known as the "pointers". They are thus called because if you follow along the line from the one at the bottom of the bowl to the one where the water would pour out and continue that direction for a short distance you will come to the north star. You cannot be mistaken as no other bright star exists in the neighbourhood. As this star group moves about the pole, due to the diurnal rotation of the earth, these two stars always keep pointing to the pole, and hence in any country where the group is

visible they tell you the direction of the north point. Strictly speaking the north star is not exactly at the pole, being a small angular distance from it, but it is sufficiently close to serve as a good guide for direction at night. Boy Scouts, moreover, know how to tell the time of night by it.

This star group is also known as the Great Bear when a larger number of the surrounding stars are taken into consideration. How we came by these names is buried in the mists of antiquity, but we can imagine how shepherds who watched their flocks and herds by night associated with various star groups the names of familiar objects or animals. Thus we have the bear, the lion, the dog, the scorpion, the dragon, the eagle, the swan and many others, and indeed some persons who delve into such matters believe they can tell the races that originated the names of constellations by the animals thus associated with the groups.

It is customary to designate the bright stars of each group by the letters of the Greek alphabet. Instead of our a, b, c, etc., they run α, β, γ, etc., and these seven bright stars, starting where the water would pour out and going back to the end of the handle, are named alpha, beta, gamma, delta, epsilon, zeta and eta of the Ursa Major group. The distances between certain ones furnishes a handy scale for estimating angular distances. We know that from the horizon to the point overhead is 90 degrees, but if we were asked for 10 degrees we might err considerably unless we had a scale to assist us. The depth of the bowl, that is, from alpha to beta, is 5°; the width at the top, that is, from alpha to delta, is 10°, while the distance from alpha to the end star of the handle eta is 26°. These come in handy.

The middle star of the handle is commonly known as Mizar. If you have good eyesight you will see a fainter one close by known as Alcor. Mizar and Alcor have been known by some as the Horse and Rider. Why, I do not know. If you have an opera glass or small telescope you will see that Mizar itself is in reality two stars, one considerably brighter than the other. This star has an interesting history. It was the first one to be observed as a double star. That was away back in 1650, shortly after the telescope was invented. These two stars are practically fixed with

respect to one another and undergo no change in their relative positions. But even more interesting is the fact that each of these double stars is again made up of two component stars so close together that no telescope will separate them. We know this from other lines of evidence, and the brighter star of Mizar again had the distinction of being the first of this type to be discovered. The close components in this case revolve about each other every 20.5 days; we do not know the period of revolution of the other pair. The naked eye companion, Alcor, also consists of two components revolving about each other in a day or so, the exact time not yet being known. Evidently the components of the latter must be almost in contact with each other.

Thinking only of the seven bright stars in the group, one would suppose that with the perfect number seven in the family there would be the utmost harmony. Such is not the case. Five of them are of similar make-up and are moving through space in a common direction, whilst the other two,—as it happens the two farthest apart—are of different type and moving in the opposite direction. This parting asunder is not appreciable within recorded times, but 100,000 years from now the outline of the group will not be recognizable as compared with the one familiar to us now.

Much more might be said about each one of the seven, but with the added information that on the average they are 100 times as bright as our own sun we will conclude by directing you to another group. If you follow out the curve of the handle of the Dipper towards the east you will come to a bright star, Arcturus, the brightest gem of the heavens during the spring and summer months. If we begin to watch for the stars in the early twilight, before it deepens into the shades of night, Arcturus is the first star that comes into view. This may account for the name given it by dwellers on the banks of the Euphrates, who called it the "Shepherd of the Heavenly Flock", the advance guard on watch for the safety of its lesser companions. Take a look and locate the Dipper and Arcturus.

STRANGE BEHAVIOUR OF A LIGHTNING STROKE

By J. P. Henderson

On March 26th, a severe electrical storm passed over Deschenes, about 5 miles north west of Ottawa. A farmer, Mr. E. E. Lusk, living in that vicinity, has the usual group of farm buildings, well protected with the lightning rods, and the house and barn which are partly roofed with metal roofing has this roofing grounded. Lightning struck the barn, the house, a windmill, a silo, the well and a fence.

With the exception of the killing of a cow the damage done was not serious,—a window broken, a fence post shattered, the inside of the silo slivered, the windmill slightly burnt, the well cover blown off and the cupboard under the kitchen sink blown out.

From an examination of the buildings it appeared that:

(a) An isolated fence post was split from top to bottom. This post forms the end of a wire fence and probably was the conductor to earth of a charge collected by the wire fence.

(b) One stroke apparently came down the inside of the wooden silo which may have been somewhat damp, although there was a lightning rod on top. Leading from the silo was a door into the cow stable, and the cow that was killed was the second from the end, and just behind her a pane in the window was shattered. The stable contained about 40 cattle and is modernly equipped in every way, including drinking bowls piped to a tank with a float to maintain constant level, which in turn is connected with the water reservoir on the loft floor, all being under the metal roof which had several lightning rods above. There did not appear to be any other damage done and there seemed to be no connection of this stroke with the water system, though of course it could not be determined whether this particular cow happened to be drinking at the time and got the shock through to the cement floor. The water tank is filled by the windmill pump through about 120 feet of underground piping.

(c) The windmill was struck. The corner of one of the galvanized fan blades was burned off for about an inch. Half way down the frame appeared vertical striations on the galvanizing on the steel, one corner member showing signs of being rather badly burnt, and at the bottom of this corner an iron bar lying on the ground happened to make electrical connection between the windmill and the well. The ends of this bar were burned and some of the stones and mortar in the side of the well dislodged. The rod operating the pump is wood, hence the stroke came down the side of the frame, jumping from there via the iron bar to the damp side of the well. The wooden lid of the well was blown off as if by pressure from within,—probably steam formed suddenly by the flash in the side of the well.

(d) The metal roof of the kitchen was burned slightly as well as the board immediately under it where the wire from the lightning rod passed over it on its way to ground. Sparks were seen after the flash at this point though no fire continued to burn. Below this is the kitchen sink, the boarding around which was blown off, apparently by an internal explosion, which may have occurred inside the drain pipe which was injured. The cellar wall, close to the water pipe from the well, had the mortar from between the stones scattered over the floor, also as though from internal explosion, caused by the electricity passing through it to ground outside and to the water pipes.

Only slight extra splaying of the strands forming the tips of the lightning rods were observable in a couple of cases—the stranded cable was designed to splay open slightly—no balls showed any injury and no burning of the tips occurred, nor was the frozen ground disturbed at their entrance to the ground. Their bases are driven straight down into a drilled hole and probably were below the frost.

The burning of the tips of any parts struck was very slight. The greatest heating and burning effects were half way down or towards the ground, which would be the case if an oscillatory discharge took place having the natural period of the object, say

the windmill tower to ground, where the loop of current would be either half way down if the tower oscillated as a hertzian oscillator by itself, or at the ground if it acted as a half oscillator, the tower being "voltage fed" by the clouds above through its tip which would not have currents of such dimensions to burn it. Also the roof showed effects of a heavy quantity of current flowing from it to the rod over the kitchen, the spark gap of the oscillator being formed by the gap between the wire and the metal roof, this probably being the only place in the whole installation where the rods or cables were not tied electrically to the metal roofs, and was probably quite accidental in its separation.

It is to be presumed that the survival of the family and the buildings was due to the effective protection of the lightning rods and grounds.

Dominion Observatory, Ottawa,
March, 1928.

NOTES AND QUERIES

Communications are invited, especially from amateurs. The Editor will try to secure answers to queries.

Weather and Health Bulletin

At a recent meeting of the R.A.S.C. at Toronto, Dr. John B. Fraser advocated the publication in the newspapers, along with the weather forecast, of precautions to be taken on account of the weather predicted. As samples he suggested the following, the one suitable for the day being printed beside the forecast.

WEATHER	PRECAUTIONS
Very Hot (Temp. 95–100°F.)	Danger of Sunstroke, Heat Stroke, Giddiness, Blinding Headache. Horses also affected. Safeguards. Seek rest and shade. Dress loosely, avoid violent exercise or excess of fatty food. Use iced drinks moderately.
Very warm (Temp. 85–90°F.)	Danger of Diarrhoea, Dysentery, Gastric Disturbance and Ptomain trouble. Safeguards. Keep body, food and milk cool. Dress lightly, avoid undue exercise, and rest when possible.
Thunder showers	Danger of sour milk and mouldy food. Safeguards. Watch baby's milk. Destroy mouldy food.
Cold and Wet	Danger of Coughs, Colds, Bronchitis, Pneumonia, Tonsilitis, Rheumatism, Pharyngitis, Laryngitis. Safeguards. Dress comfortably. Keep the feet dry, avoid wet clothing, damp sheets, draughts of cold air or standing still on a wet, cold pavement.
Very Cold (Zero)	Danger of frost bites, Pneumonia, Pleurisy and chilled body. Safeguards. Dress warmly, avoid chills. Keep living rooms comfortable, avoid super-heated, and impure air and use more fats in your diet.

The Copernican Intellectual Revolution

The writer of an article on "Sir Thomas Browne," in the *Times Literary Supplement* for May 21, 1928, gives the following lively account of the effect on the intellectual world of the astronomical discoveries at the time of Copernicus:—

It had been supposed, for example, for a millenium and a half that the earth was the stationary centre of a finite universe, and that the sun went round it. It was now asserted and indeed proved—though the majority of thinking men, with Bacon and Sir Thomas Browne among them, refused to be convinced—that the earth was not the centre of a finite universe, but only one among innumerable revolving bodies in a vast immensity of space; nor was it stationary, but revolved about the sun. We can but dimly imagine the shock of these assertions, of this terrestrial dethronement, to learned and devout men; for "the new philosophy" hit learning and religion. It was the pride of the Catholic Middle Ages to have forged into one system the Ptolemaic and the Christian universe, and so compactly riveted them together that one, it seemed, could hardly fall without the other. It was a wedding, as tight and fast as a learned Church could make it, of science and religion. We cannot wonder, then, that Copernicus, the Polish Canon, concealed his discovery of the revolutions of the heavenly bodies until the year of his death, and only published by entreaty in 1543 what he had discovered thirty-five years before; or that his successor, Galileo, continued to teach the old errors from his Chair in Padua, and delayed his revelations until the appearance of a new star in the year 1604 set all the heads of Europe shaking, and supplied him with a text.

It was a great event, that star. You will find it in Bacon, in Donne, in Burton, in Browne, in Ben Jonson; every one talked of it, and drew, or shrank from drawing, his own conclusions from it. It was not indeed the first occurrence of the kind. Early in that same generation, in 1572—when, as Spedding reminds us, Bacon was a Cambridge freshman—a new star had appeared, as bright as Jupiter, and had then incontinently gone out. It was hoped that it would be the last of its species, that Nature would recollect herself and relapse into her pre-ordained decorum. But here, within a single generation, was another! It may be asked by a modern reader, why all this fuss? They should have been interested and pleased. They were certainly interested. For by these two extravagances of Nature another cherished belief had been upset. It was an axiom of Christian astronomical theology, and had been an axiom for centuries, that the Firmament is Unchangeable and Incorruptible; and here were these very heavens suddenly lighting up, and presently extinguishing, in the very region of the Immutable, one new star after another, protesting by signs and wonders against the cardinal doctrine of the old natural philosophy, which was also, by incorporation, the doctrine of the Christian Church. Can it be wondered that on these, as on other counts, some men turned sceptics? How do we know that we know anything? C. A. C.

NEWS AND COMMENTS

At a meeting of the National Committee of Canada, called by Chairman R. Meldrum Stewart at Winnipeg, May 23, the following delegates to the International Astronomical Union meetings at Leiden were elected: Prof. D. Buchanan, Prof. C. A. Chant, Prof. A. S. Eve, Dr. F. C. Henroteau, Prof. L. V. King, Prof. A. H. S. Gillson, Dr. J. S. Plaskett. Dr. Plaskett sailed on June 8, Dr. Chant on June 22.

The primary clocks of the Dominion Observatory are now being transferred to the underground clock-vault built last year. A "Synchronome" clock will be added. The temperature of the vault is automatically maintained at 20°C. within very narrow limits.

Mr. A. H. Miller of the Dominion Observatory sailed for England on June 8 to study the torsion balance in association with the Geological Survey of Great Britain, on behalf of the Geological Survey of Canada as well as of the Dominion Observatory. He will also make measurements of gravity at London and Berlin with the instruments used for this work in Canada, and the comparative measures will be of value in studies of the Earth's figure.

Mr. J. A. Pearce of the Dominion Astrophysical Observatory is on leave to conduct the summer courses in astronomy at the University of Toronto.

Mr. H. H. Plaskett, on leave to give a course of lectures on astrophysical subjects at Harvard University, spent the June intermission in photometric research at the Dominion Observatory.

Editor C. A. Chant of this JOURNAL and Editor C. H. Gingrich of *Popular Astronomy* are attending the Leiden meetings of the International Astronomical Union, so that readers of these periodicals may expect to see complete accounts of the proceedings.

For the past four years the Dominion Observatory has broadcasted time signals through the Ottawa stations CKCH or CNRO, and occasionally through CNRT and CHRM; and for some months

broadcasts on small wave-length (52.5m.) have been made directly from the Observatory, and the Surveys Bureau is arranging to use these signals in the field this summer. It is to be hoped that eventually time signals will be sent from stations covering the whole of Canada.

The following student-assistants are engaged for the summer months at the national observatories: At Ottawa: Mr. W. H. Christie, M.A., Miss Alice W. Turner, M.A., Miss W. D. Woolcombe, B.A., and Mr. Malcolm Robertson. (Mr. Ralph H. Hawkins, B.A., was prevented by illness from accepting an appointment, and Miss Dorothy Osborne was a volunteer assistant during June.) At Victoria: Mr. P. M. Millman and Mr. R. M. Petrie.

Houyhnhnmity

Twinkle, twinkle little star,
They failed to find out what you are:
And so to poetry turned our "Staff",
While you, winged Pegasus, had a laugh! (J.F.D.)

A device is being constructed at the Dominion Observatory for reading directly the heliographic coordinates of points on the solar disc which have been observed spectroscopically or of images of sunspots on photographic plates of the sun. It consists of a sphere graduated in degrees and adjustable for the changing latitude of the centre of the solar disc, surmounted by a graduated coordinate frame which can be set at any position angle around the limb. A vertical projector will throw the image of a solar photograph down on a disc resting on the frame. R. E. DeL.

MEETINGS OF THE SOCIETY

MEETING OF THE GENERAL COUNCIL OF THE SOCIETY

A meeting of the Council of the Royal Astronomical Society of Canada was held on April 11th, 1928, in the Meteorological Office, Bloor St., Toronto, at 8 p.m.

The following were present:—Professors C. A. Chant, J. Satterly, H. R. Kingston, L. Gilchrist, Rev. Dr. D. B. Marsh, Dr. E. T. White, Messrs. J. H. Horning, E. J. Kennedy, W. E. W. Jackson, H. W. Barker, J. R. Collins, A. F. Miller, A. F. Hunter, and Dr. R. K. Young, the Vice-President, who was in the chair.

The minutes of the meeting held November 25th, 1927, were read and approved.

Correspondence dated March 12th and April 2nd, 1928, from W. E. Harper, President, was read by the Chairman.

Mr. Hunter read from the Assistant-Secretary's notes the amounts that had been received from the various Centres during the past year.

Moved by Dr. Chant, seconded by Dr. Kingston, that the grants to each Centre be 50% of the amount received from each Centre during the calendar year just closed, and that the Committee of the Vice-President and Treasurer, in the case of hardship at any Centre, be empowered to advance such amount as they think necessary for carrying on the affairs of the Centre. Carried.

Discussion took place over the allocation of membership to the Centres. Moved by Mr. Hunter, seconded by Mr. Miller, that each member not already allocated to any Centre, elected to the membership of the Society, be asked to specify the Centre to which he wishes to be attached. Carried.

Mr. J. A. Pearce having been elected a member of the Council by ballot, and being a member as President of Victoria Centre, thus leaving a vacancy in Council, it was moved by Mr. Hunter, seconded by Dr. Chant, that Mr. R. A. Gray be elected a member of the Council to fill the vacancy. Carried.

A communication was received from the Royal Society of Canada inviting the R.A.S.C. to appoint a delegate to the meetings in Winnipeg in May, 1928. It was moved by Dr. Kingston, seconded by Dr. Chant, that Professor L. A. H. Warren, of Winnipeg, be the representative of the Society at the meetings of the Royal Society of Canada. Carried.

A communication was received from J. H. Wicks, Librarian of the University College Library, University of London, requesting that the

Society replace copies of the JOURNAL which they do not now have in hand. Moved by Prof. Satterly, seconded by Mr. Hunter, that Dr. Chant and Dr. Gilchrist send these copies to the University College Library, and also request them to send the missing copies of the British Association Reports in our library. Carried.

Moved by Mr. Barker, seconded by Dr. Marsh, that in addition to the grants to each Centre on the basis of membership, that each Centre be encouraged to secure civic grants or private donations. Carried.

Moved by Mr. White, seconded by Professor Gilchrist, that the Vice-President send the substance of the letters of the President to the Council, to the Presidents of the Centres, that will be of assistance and encouragement to the Centres. Carried.

Moved by Mr. Hunter, seconded by Mr. Miller, that the question of use of the Society's telescope, and the question of better accommodation for the library be referred to the Toronto Board. Carried.

Moved by Dr. Chant, seconded by Mr. Hunter, that the Toronto Board be requested to designate the person to whom the grant for local expenses be paid. Carried.

The meeting then adjourned.

L. GILCHRIST, *General Secretary.*

AT MONTREAL

January 20, 1928, in the Macdonald Physics Laboratory, McGill University. The chair was taken by Mr. H. E. S. Asbury

The lecturer, Dr. Annie J. Cannon of Harvard Observatory, was introduced by Dr. A. S. Eve.

Dr. Cannon began with a reference to the 1843 comet whose appearance awakened wide interest in astronomy and led directly to the founding of Harvard College Observatory. Its 15 inch refractor was the largest telescope at the time of its erection in 1847. With it the first star photograph was taken in 1850. This Observatory now has over 300,000 photographs upon which are probably 10^9 star images.

The spectra of stars were then discussed with reference to the early visual classification of Secchi and the subsequent Henry Draper Classification. With the completion of the H. D. Catalogue of 225,300 star spectra, giving as it does all the stars to 6th magntiude, the lecturer's work is in no sense finished, but rather just begun, for Charlier and the other astronomical statisticians require all the stars to 15th magnitude similarly classified. This gigantic task is now in progress upon plates 8×10 inches, each one of which contains some 3000 stars to 12th magnitude.

Slides were shown of the rich starfields in Sagittarius, of plates upon which variable stars were identified; of globular clusters, 90 of which are known; of Arequipa 8000 feet up in the Andes where so many of the Harvard photographs have been taken.

Special mention was made of the problems connected with Novae, so many of which are being found in the spiral nebulae. Here as elsewhere the astronomer looks for and studies the changes which take place, and from the evidence of change, the laws of change may be deduced.

The thanks of the Society were voiced by the Secretary, who referred to the inestimable debt of gratitude which every astronomer and astrophysist owes to Dr. Cannon for the herculean task which she has accomplished in the Henry Draper Catalogue. The vote of thanks being unanimously carried, the meeting adjourned.

February 23, in Macdonald Physics Laboratory, McGill University. Mr. H. E. S. Asbury, Vice-President, took the chair.

Mr. J. O. Bousquet was elected to membership.

The Chairman called upon the Honorary President, Mgr. C. P. Choquette, to address the Society upon the 1927 Eclipse and his trip to various European countries on that occasion.

Mgr. Choquette spoke first of Stonyhurst (Lancs.) and their equipment for making astronomical and magnetic observations; then of Greenwich and Paris Observatories. At Paris he also visited the small popular observatory where a 9-inch and a 4-inch telescope are available and lectures are given for public instruction. From Toledo, his furthest south, he journeyed north to Copenhagen, visiting the ancient tower from which Tycho Brahe and Kepler once observed the heavens, and thence he went to Oslo and to a village N.W. of Oslo in latitude 61°N., where Professor Mitchell and an American party had set up instruments. Unfortunately on June 29th there were light clouds which prevented the party from observing the full grandure of the eclipse, though the coming and passing of the shadow were very spectacular. Duration of totality was 33 seconds. Professor Mitchell stated that the eclipse began within 0.5 sec. of the predicted time.

The lecturer reported that at Stonyhurst no magnetic deviation was recorded during the time of the eclipse.

The Chairman then called upon Col. W. E. Lyman, who with his family had likewise journeyed to Norway to see the eclipse. Col. Lyman described what they saw of the eclipse, showing several clear slides from photographs, knidly given by Professor Mitchell, of the solar crescent reappearing after third contact. He then described a trip up the coast of Norway, showing some very beautiful slides of he fjords, culminating in the spectacle of the midnight sun, successful photographs of which were taken by Miss Lyman and reproduced in slides.

After a hearty vote of thanks had been tendered the speakers, the meeting adjourned.

April 5, in Macdonald Physics Laboratory, McGill University. In the absence of both vice-presidents, the chair was taken by Mr. Joseph Lutrell.

The Secretary referred briefly to the loss sustained by the Society in the death of Mr. S. G. McElwaine.

The lecturer was Dr. D. A. Keys, F.R.S.C., his subject being "The Properties of Light".

Beginning with the nature and production of images, Dr. Keys illustrated by experiment the pinhole camera, real and virtual images, multiple images. He then constructed models of the Newtonian and Gregorian telescopes.

Passing on to refraction and total reflection he caused a beam of light to pass through a glass water bath and by inserting various lenses in the path of the beam he showed clearly the phenomena of convergence and divergence. A Galilean telescope was then constructed. Colour was next dealt with and the spectroscope explained. By means of various salts and an arc light typical emission spectra were produced and superimposed upon a continuous spectrum.

At the conclusion Col. Lyman and Mr. J. A. Wright expressed their gratitude to the lecturer for his delightful presentation of the subject.

May 3, at 8.15 p.m., in the Macdonald Physics Laboratory, McGill University. The chair was taken by Col. W. E. Lyman.

Two new members were elected,—

Mrs. W. E. Lyman,

Mr. A. L. Roberts.

The Chairman called upon Mr. George Sample to address the Society. Phenomena of Mind, Geometry and the Planets was the subject of his very unusual and interesting discourse.

Beginning with some remarks upon the mind of man and the evidence of order and in particular of geometry in nature, the lecturer made reference to the statement of Herbert Spencer, "Uninterrupted corespondence with a perfect environment is life eternal." He pointed out that a link between science and religion is to be found in the passage taken in conjunction with the verse of scripture, "This is life eternal to know Thee. . . . ." Passing on to the main subject of his address, Mr. Sample showed diagrams of various regular polygons inscribed in a circle and explained how the ratios of certain lines in the diagrams, both sides and apothems, gave very closely the ratios of the distances of the planets from the sun. Extrapolating to the hypothetical planet beyond Neptune the lecturer finds its distance to be 40 astronomical units or 3729.9 million miles and because the isosceles triangle plays a prominent part in this diagram, he calls this planet Isos. Several members informally expressed their appreciation to the lecturer, but on his request no formal vote of thanks was passed and the meeting closed with the National Anthem.

A. Vibert Douglas, *Secretary.*

AT WINNIPEG

The regular meeting of the Royal Astronomical Society was held in lecture theatre A, March 14, with the President in the chair.

Mrs. Taylor, in opening, referred to two interesting articles in the January JOURNAL. One of great interest to us was our member Mr. Megget's "Plea for Better Knowledge of the Stars." Mr. Megget has distributed many copies of his paper. The other was the account of the life of Mr. J. Brashear, "Uncle John," whose life began in such a humble way and ended so brilliantly. Glowing tributes were paid to his memory by members of the society.

Mr. C. E. Bastin, the first speaker of the evening, gave a very interesting and instructive talk on Jupiter and Saturn. He spoke of the great amount of work done in late years, in astronomy. Remarkable advance was made in the study of distant stars and island universes, though we must not suppose that the problems of the nearer bodies were fully solved by any means. Galileo was the first to see the moons of Jupiter in 1610 with his small telescope. Since then much has been learned of his belts, spots, dimensions and colours of these, and significance of the colours. By careful observation, we can determine the rate of rotation, and a complete map of Jupiter could be made in one night, a little over ten hours. Of deep interest is the "great red spot" of Jupiter, which fades out and seems to recover somewhat again. The motion of the equatorial belt or band is faster than those towards the poles, probably 250 miles an hour. This causes a tremendous current which we cannot realize, knowing that wind moving on the earth at 80 miles is a hurricane. The circumference of Jupiter is about 275,000 miles and the whole surface seems to be in commotion being neither solid nor fluid. The density of Jupiter is 1.34, while that of Saturn is only .7, and the latter would float on water. Up to twenty years ago, it was supposed that Jupiter was hot, but in 1914, observations showed that we receive no heat from it but that which the sun supplies. Its temperature, –220°F., and six-year long winters, quite reconcile us to our own on earth. Layer upon layer of cloudy blankets forming the bright bands keep heat from being thrown off and also outside heat from penetrating them. But these conditions are as yet seen only "as through a glass darkly" and many problems nearer home may still be studied with advantage.

Mr. Megget spoke on motion and made some of his hearers dizzy with the rate he carried them mentally through space. And from the contemplation of vast suns thousands of light-years away travelling at almost a million miles an hour, he came back to the consideration of the atom, infinitesimally small, but compared with whose rate of motion the stars move very slowly indeed. Then for a better understanding, man's rate of locomotion and achievement in transportation were compared with these

other bewildering rates, which make us feel we are standing still while the whole universe goes by.

Mr. Saunders then gave a very clear and enlightening talk on lenses. Galileo discovered that with the use of two glasses the objects were magnified, and he managed to produce a small telescope. From the pin-hole camera on to the latest triumph of the scientist for observation of the heavens was marvelous indeed. Several fine slides were shown from the transition of the smallest telescope to the Victoria one, which is the second largest in the world. It is interesting to read of the first known telescope, referred to by Hale in his "New Heavens." This is supposed to have been made by Tut-anhk-Amen, who speaks of it as "made by my own two hands." We read that Herschel began life as a musician, but later becoming interested in astronomy, he began to make telescopes. He became one of the greatest of astronomers and one of the best makers of telescopes.

JEAN C. HOWEY, *Sec. pro tem.*

The Royal Astronomical Society of Canada

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